the extinction of ammonium sulfate aerosol typical of the mid- to high-troposphere background aerosol. At the same time, the scattering of the aerosol was measured, and an estimate of its single-scatter albedo could be made. It is expected that continued development of this technology will lead to a flight-ready instrument within the next two years.

T. Owano, Informed Diagnostics, Inc., collaborated on this project.

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The Runaway Greenhouse Effect on Earth and Other Planets

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Water vapor is an efficient absorber of outgoing longwave infrared radiation on Earth and is, therefore, a primary greenhouse gas. Since the amount of water vapor in the atmosphere increases with increasing surface temperature, and the increase in water vapor further increases the temperature, there is a positive feedback. The runaway greenhouse effect occurs if this feedback continues unchecked until all the water has left the surface and enters the atmosphere. For Mars and Earth, the runaway greenhouse effect was halted when water vapor became saturated with respect to ice or liquid water, respectively. However, Venus is considered to be an example of a planet where the runaway greenhouse effect did occur, and it has been speculated that if the solar luminosity were to increase above a certain limit, it would also occur on Earth.

Satellite data acquired during the Earth Radiation Budget Experiment (ERBE) clear sky conditions shows that as the sea surface temperature (SST) increases, the rate of outgoing infrared radiation at the top of the atmosphere also increases, as expected. Surprisingly, above 300 kelvin (K) the outgoing radiation emitted to space actually decreases with rising SST. Less energy to space implies that more energy is available to heat the surface, leading to a potentially unstable situation. This behavior is a signature of the runaway greenhouse effect on Earth. However, the SST never exceeds 303 K, thus the system has a natural cap that stops the runaway.

According to Stefan-Boltzmann's law, the amount of heat energy radiated by the Earth's surface is proportional to temperature $(T)^4$. However, if the planet has a substantial atmosphere, it can absorb all heat radiation from the lower surface before the radiation penetrates into outer space. Thus, an instrument in space looking at the planet, does not detect radiation from the surface. The radiation that it detects comes from some level higher up in the atmosphere. The effective temperature (T_e) is the temperature of this emitting region within the troposphere; lower levels may have much higher temperatures. On Earth the average temperature of the surface is 288 K, but the effective temperature is only 255 K. The value T_e = 255 K corresponds to the middle troposphere, above most of the water vapor and clouds.

Atmospheric instruments and sensors on high-altitude aircraft, radiosonde, and satellite platforms provide direct observations of sea-surface temperatures, outgoing infrared flux to space, and atmospheric humidity and temperature profile measurements. The ERBE data is now being used to model the sea-surface temperature and outgoing flux to space. The aim is that this radiative transfer model will reproduce the signature of the potential runaway greenhouse effect on Earth (figures 1 and 2). The model will be a link between ERBE measurements and theory and will help us to understand climate evolution and divergent climates of Venus, Earth, and Mars, as well as the inner boundary of the habitable zone in other planetary systems.

The significance of the observed sea-surface temperature at which the outgoing longwave radiation to space begins to decrease, as well as the observed upper limit on the sea-surface temperature, is that both phenomena are relevant to several aspects of paleoclimatology and astrobiology. This model will be used in an attempt to predict the upper limit of sea-surface temperatures for different values of atmospheric carbon dioxide (CO_2), an objective directly relevant to understanding past and future climate states of the Earth. For example, did these same processes prevent the oceans from evaporating during past climate episodes of enhanced CO_2? Evidence suggests that even during past climates SST did not exceed 303 K. The runaway greenhouse effect is thought to be a critical factor in defining the inner edge of the habitable zone of any planetary system, therefore an understanding of the phenomenon on Earth and in our own solar system is of great importance.

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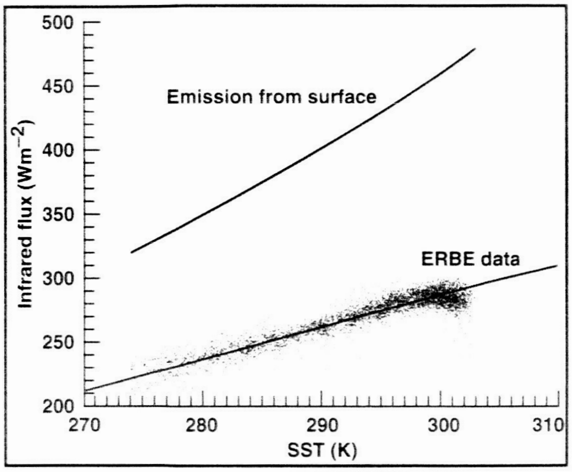

Fig. 1. According to Stefan-Boltzmann's law, the amount of heat energy radiated by the Earth's surface is proportional to $(T)^4$ (upper line). The output from MODTRAN, i.e., the modeled Top of Atmosphere Emission, is also displayed (lower line). The model incorporates user defined atmospheric pressure profiles and temperature profiles based on a moist adiabatic lapse rate as well as relative humidity profiles. Together these profiles give the best modeled fit (up to an SST of 300 K) to the Top of Atmosphere Emission.

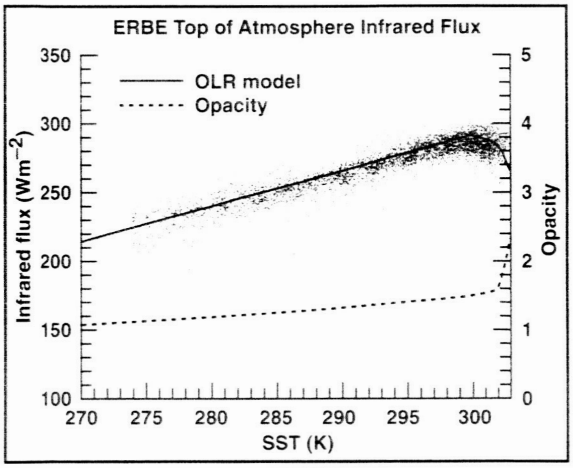

Fig. 2. The radiative transfer model was then used to reproduce the signature of the potential runaway greenhouse effect on Earth. For SST values 301-303 K, much higher concentrations of water vapor were introduced into the atmospheric profile. As a result, a turnaround and decrease in the outgoing longwave radiation model was achieved (solid line through ERBE data points). Also shown is the corresponding sharp increase in atmospheric opacity (dashed line).